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A High Spatial Resolution Study of the Thermospheric Response to a Discrete Auroral Arc

R.W. EASTES   L.H. BRACE
T.L. KILLEEN   W.R. HOEGY
G.R. CARRIGNAN   R.A. HEELIS
A.E. HEDIN   J.D. WINNINGHAM
N.W. SPENCER   B.A. EMERY

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AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MA 01731

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"This technical report has been reviewed and is approved for publication"

FOR THE COMMANDER

Robert E. Huffman

ROBERT E. HUFFMAN, Chief
UV Surveillance & Remote Sensing Branch

Robert A. Skrivanek

ROBERT A. SKRIVANEK, Director
Ionospheric Physics Division

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A sequence of three high latitude passes by the DE-2 spacecraft has been studied using high spatial resolution data from several instruments to investigate the local thermospheric response to a discrete auroral arc. Three passes, orbits 1847, 1848, and 1849, which occurred on 6 December 1981, cross an isolated, discrete arc in the evening auroral oval. Observations of neutral winds, ion winds, neutral densities, energetic electron spectrum, and neutral temperatures were examined at a spatial resolution of ~8 km. The observations illustrate the response of the thermosphere to the local insertion of energy and momentum and provide the basis for a more critical test of the various theoretical models that have predicted local thermospheric phenomena. The results are presented and discussed in relation to the predictions of three such local models.

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1. INTRODUCTION

The dynamics of the Earth's thermosphere near discrete auroral arcs has not been adequately studied at high (< 25 km latitudinal) spatial resolution. Large scale modeling of the response of the neutral thermosphere to ion convection has successfully explained many of the experimental observations of the neutral winds at high latitudes. However, the large scale models mask the small scale structure in both the electric field and the ion density produced by discrete aurora. The primary sources of ion drag and Joule heating are sensitive to the distribution of both sources and their spatial relationship. Recently, several high resolution models[1,2,3,4] of the dynamics of the lower thermosphere near discrete auroral arcs have been developed. All the models examine the response of the neutral thermosphere to electrodynamic forcing for discrete auroral features with widths of ~100 km (Figure 1). The only published data with spatial resolution adequate for comparisons with these models are from rockets that can give only local measurements. Such local measurements are not sufficient to test these models adequately; however, the Dynamics Explorer (DE-2) satellite

1. Fuller-Rowell, T.J. (1984) A two-dimensional, high-resolution, nested-grid model of the thermosphere 1. Neutral response to an electric field "spike", *J. Geophys. Res.* **89**:2971-2990.

2. Fuller-Rowell, T.J. (1985) A two-dimensional, high-resolution, nested-grid model of the thermosphere 2. Response of the thermosphere to narrow and broad electrodynamic features, *J. Geophys. Res.* **90**:6567-6586.

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4. Walterscheid, R.L., Lyons, L.R., and Taylor, K.E. (1985) The perturbed neutral circulation in the vicinity of a symmetric stable auroral arc, *J. Geophys. Res.* **90**:12235-12248.
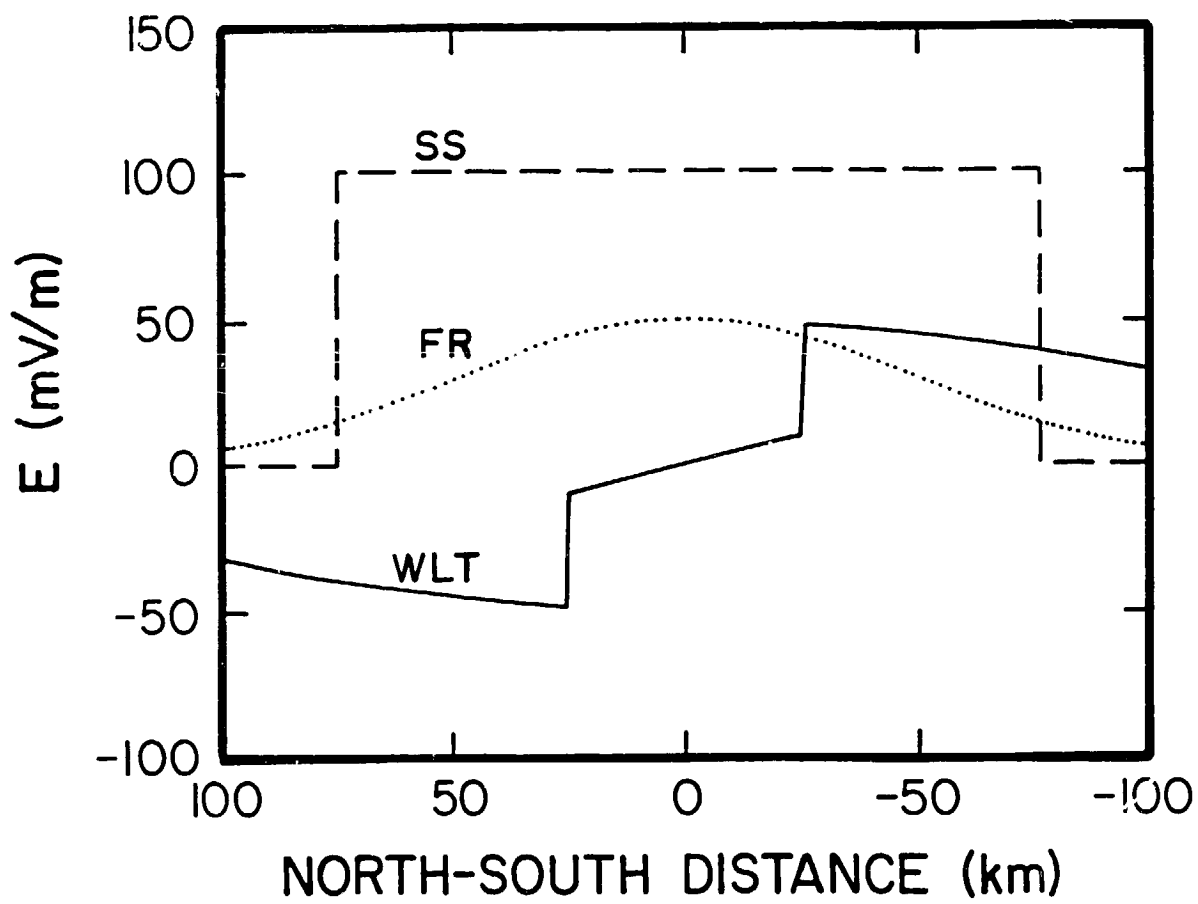
Figure 1. The Latitudinal Profiles of the Electric Fields Used in the Models by Fuller-Rowell[1,2] (FR), St. Maurice and Schunk[3] (SS), and Walterscheid, Lyons, and Taylor[4] (WLT). The distances are from the center of the arc.

provides an ideal data base for such comparisons. Here we present a high spatial resolution study of DE-2 data suitable for such comparisons.

2. DATA SELECTION CRITERIA

The data selected for this study depended on several criteria. The most crucial criterion is the spatial resolution. Since the DE-2 satellite moves horizontally by ~8 km in 1 second and the spatial scale of the features being studied is on the order of 100 km, data at ~1 second intervals (or less) are clearly desirable (and available) for parameters with similar spatial variability. Most DE-2 data published are averages over 8- to 16-second time periods, which are unsuitable for this study.

Temporal resolution is also important. The models indicate that the thermosphere takes on the order of an hour to reach equilibrium in response to a discrete auroral feature, making repeated observations of a spatially stable arc desirable for comparisons of data and models. Such an arc would be observable on a series of orbits (since the orbital period is ~1.5 hours) allowing study of the evolution of the arc. A single discrete arc is therefore preferable to multiple arcs.

The availability of data is also important. The electron temperature (measured by LANG[5]), ion density (measured by LANG[5]), ion winds (measured by IDM[5] and RPA[5]), composition of the neutral atmosphere (measured by NACS[5]), energetic electron spectrum (measured by LAPI[5]), and neutral winds (measured by FPI[5] and WATS[5]) were all measured by instruments on the DE-2 satellite, but they are not always available. For comparisons with models, measurements from all of these instruments are useful.

3. DATA FROM ORBITS 1847, 1848, AND 1849

Considering the criteria discussed, data from orbits 1847, 1848, and 1849 were selected. This series observes one of the most stable single arcs seen in the dusk auroral oval during December, 1981 for which suitable data from LAPI[5], LANG[5], IDM[5], NACS[5], WATS[5], and FPI[5] are available. Unfortunately, data from the RPA[5] was not available during these observations. The data from the LAPI[5], LANG[5], IDM[5], and NACS[5] instruments used in this study are at 1 second intervals. The WATS[5] data are at 2- to 8-second intervals, and the FPI[5] data are at 32-second intervals.

During December 1981 the orbit of DE-2 was in a dawn-dusk plane. While crossing the dusk-side auroral oval, the altitude of the satellite (~320 km) was closest to the altitudes used in the models discussed earlier. All 3 orbits crossed almost the same region of the auroral oval as shown in Figure 2, a plot of the subsatellite point in magnetic coordinates.

Some geophysical parameters associated with these observations are shown in Figure 3. The observations were during a relatively undisturbed period, and the interplanetary magnetic field (IMF) B_y is positive and B_z is negative. The arrows marking the times of the 3 orbits on the magnetic field plots have been shifted 1 hour to later times, to approximately compensate for the propagation time of the solar wind.

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5. Hoffman, R.A., Hogan, G.D., and Maehl, R.C. (1981) Dynamics explorer spacecraft and ground operations systems, *Space Sci. Inst.* **5**:349-367.
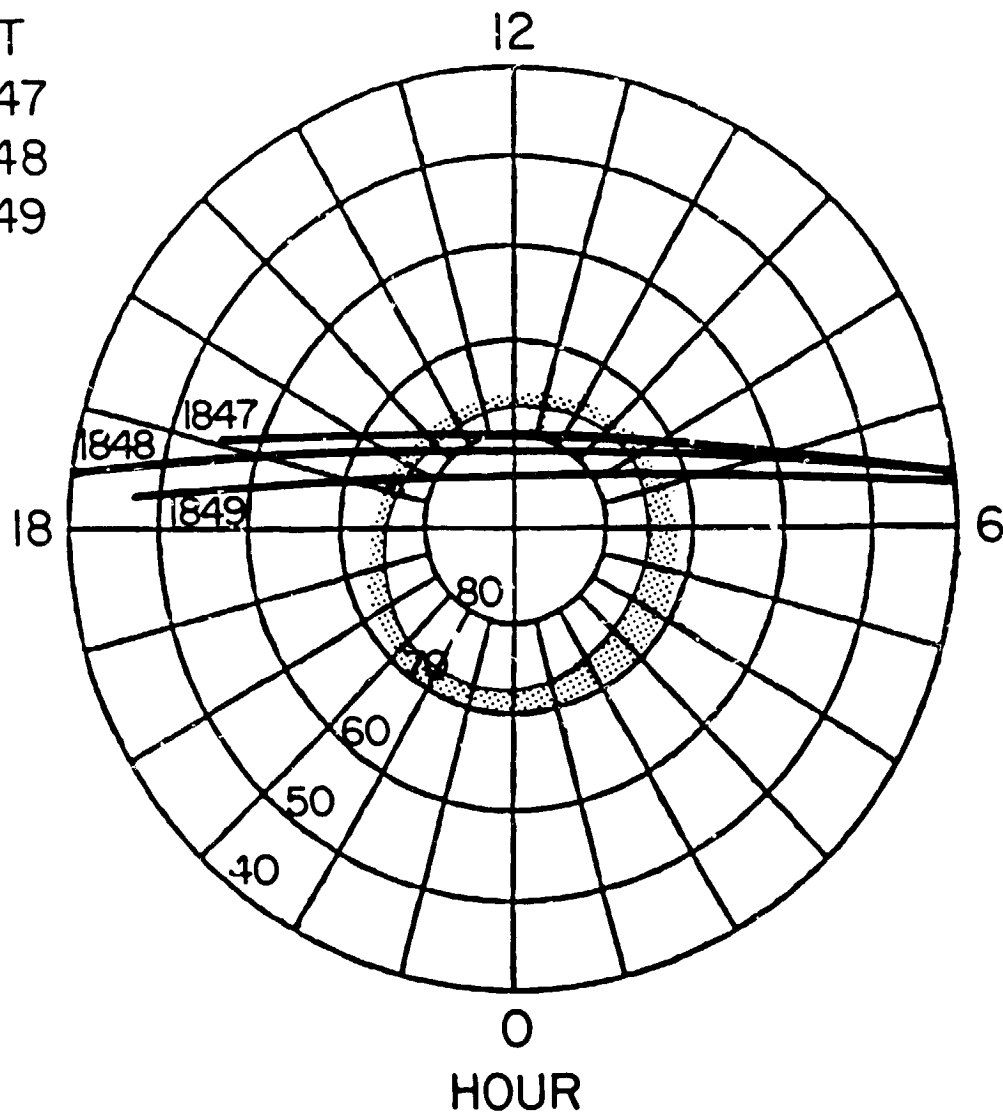
Figure 2. Orbits 1847, 1848, and 1849 by Dynamics Explorer 2, shown in magnetic coordinates (invariant latitude and magnetic local time). The shaded area is the Feldstein statistical auroral oval as parameterized by Holzworth and Meng.[6]

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6. Holzworth, R.H. and Meng, C.-I. (1975) Mathematical representation of the auroral oval, *Geophys. Res. Lett.* **2**:377-380.
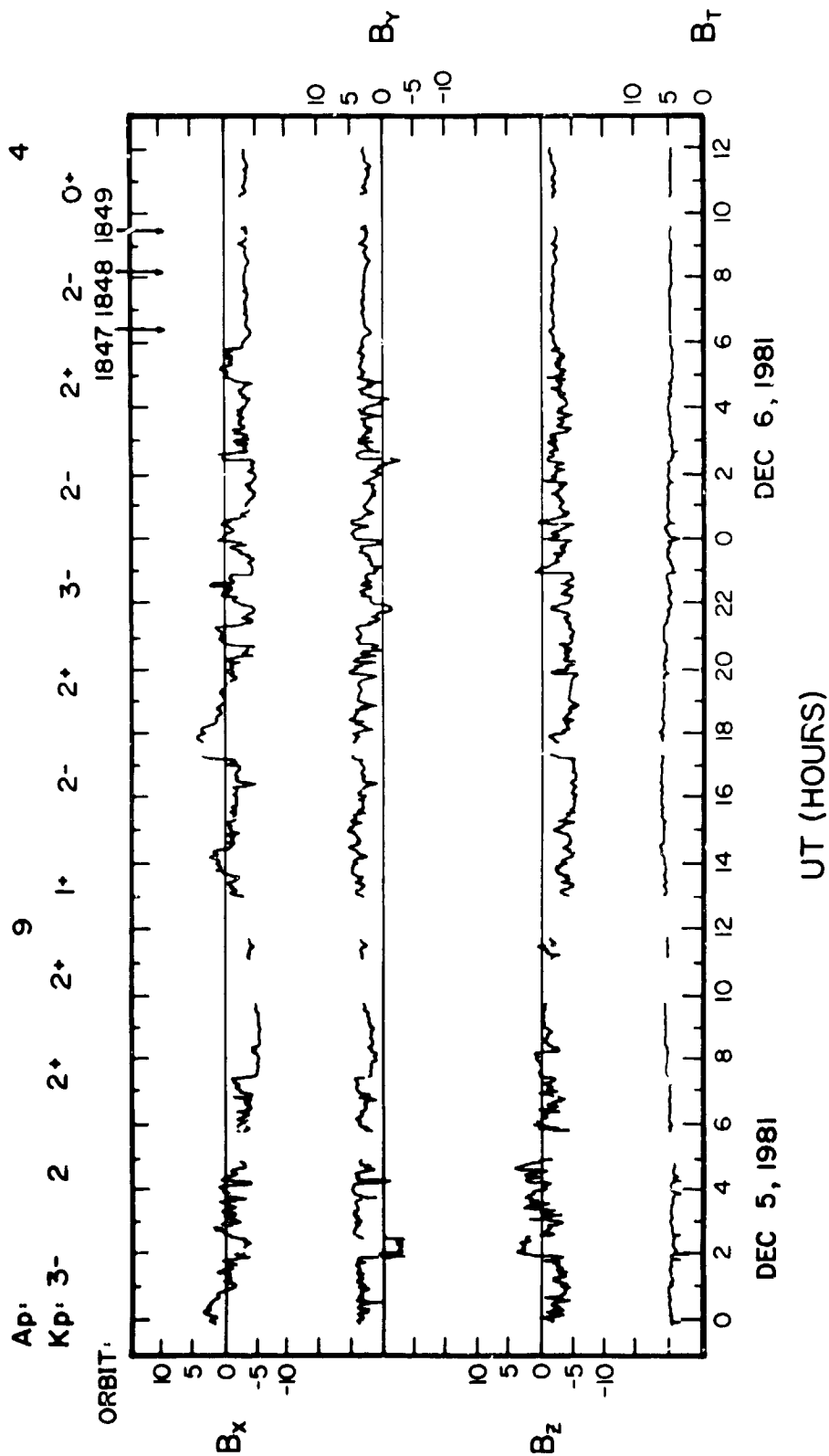
Figure 3. Geophysical Parameters Associated With the Observations. The arrows indicate the time + one hour at which the Dynamics Explorer 2 satellite crossed the auroral oval in the dusk sector. One hour was added to compensate for the propagation time of the interplanetary magnetic field since the ISEE satellite, which made the measurements plotted here, was between the Sun and Earth.

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4. DISCUSSION OF THE DATA

Shown in Figure 4 is data from the dusk side of the northern auroral oval during orbit 1849 by DE-2. Although numerous discrete auroral arcs (inverted V's) are present in the electron spectra seen on the dawn side of the auroral oval, there is only one such structure in the dusk side of the auroral oval, and it is associated with the spike in the energy input (Q_{in}) shown in the top panel. The second and third panels in Figure 4 contain the electron temperature (T_e) and ion density (N_i) data; both reflect the presence of energetic electron precipitation.

The zonal components of the ion (U_i) and neutral (U_n) winds are shown in the fourth panel while the meridional component of the neutral wind (V_n) is shown in the fifth panel. The positive zonal velocities are sunward, and positive meridional velocities are in the direction of the spacecraft velocity vector. Large neutral wind velocities toward the north pole are observed, as shown in Figure 5, a polar plot of the neutral winds. The peak electric field strength seen in the dusk auroral oval is ~50 mV m^{-1}, and ~70 mV m^{-1} in the dawn aurora.

The vertical components of the ion (W_i) and neutral (W_n) winds are exhibited in the sixth panel, and the neutral temperatures (T_n) are shown in the seventh panel. In the dawn side of the oval, the temperature of the neutral atmosphere increases, but such an increase is not seen in the dusk sector. Heating of the neutral atmosphere is also reflected by the increase in the molecular nitrogen density (relative to the atomic oxygen density) shown in the last panel. These densities have been normalized to 300 km using a barometric law correction $(e^{-mg/kT})$ where $T = 1200. - [1.5 \times$ (geometric latitude)] in an attempt to remove the altitude dependence of the densities.

Figures 6 and 7 show data from the same region of the oval during the previous orbits, 1848 and 1847. The discrete auroral arc seen in the dusk auroral oval in orbit 1849 (Figure 4) is seen in these orbits also.

The measured values for all three orbits are similar. The neutral wind patterns and velocities, in the zonal direction, are almost identical for the earliest two orbits with maximum velocities between 300 and 400 m s^{-1} (Figures 6 and 7). For orbit 1849 (Figure 4) the maximum velocity has increased to ~600 m s^{-1}, and the maximum is poleward of the maxima in the previous two orbits, reflecting a poleward shift in the arc.

The most surprising observation in these data is the minimum in the neutral temperatures. These minima are correlated with the maxima in the neutral wind velocities, and for orbits 1847 and 1849, the lowest temperatures are 100 K less than the adjacent atmosphere. Such a temperature minimum has not been previously identified, and it is unexpected considering the Joule and particle heating in the region. This temperature minimum cannot be attributed to vertical winds since maximum velocities of less than 30 m s^{-1} are seen in all three.

5. COMPARISON OF THE DATA AND MODELS

As noted earlier, the temperature of the neutral atmosphere (T_n) displays an unexpected minimum in the dusk side of the auroral oval. This minimum is seen in all 3 orbits and it is correlated with the maximum in the zonal component of the neutral wind (U_n) (see Figures 4, 6, and 7).
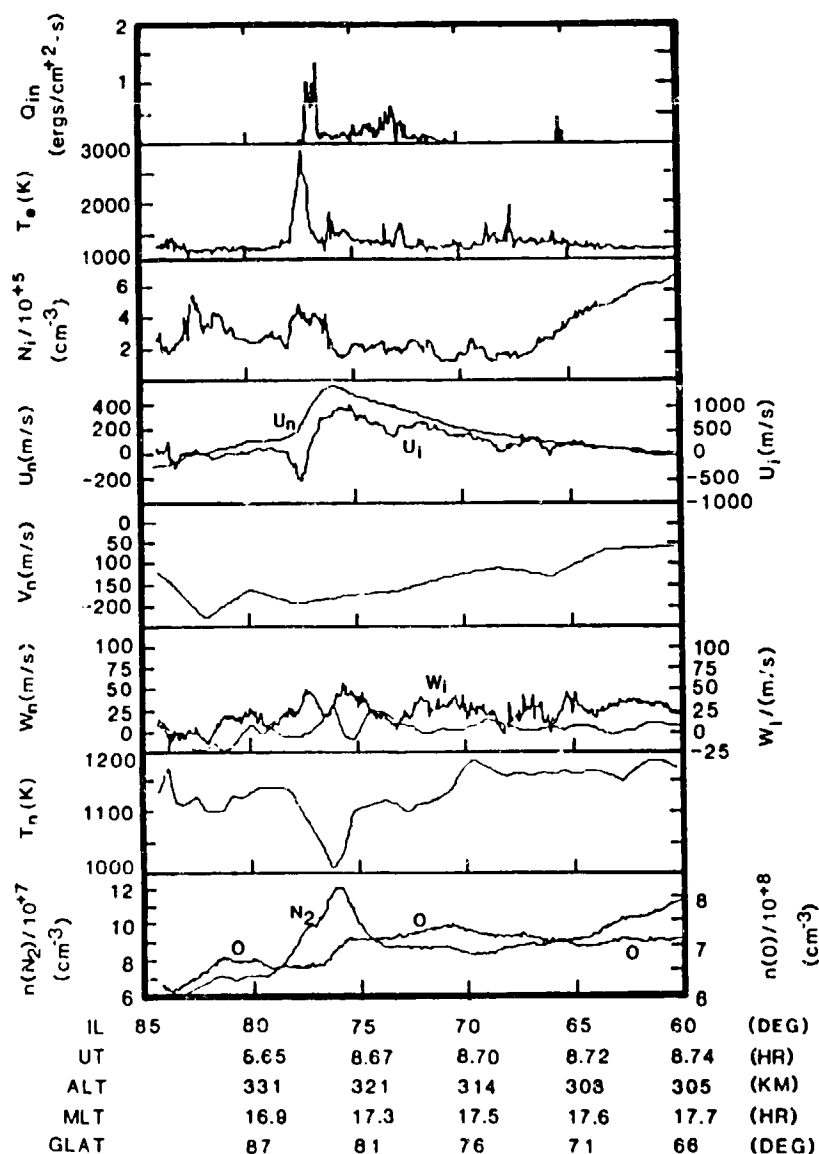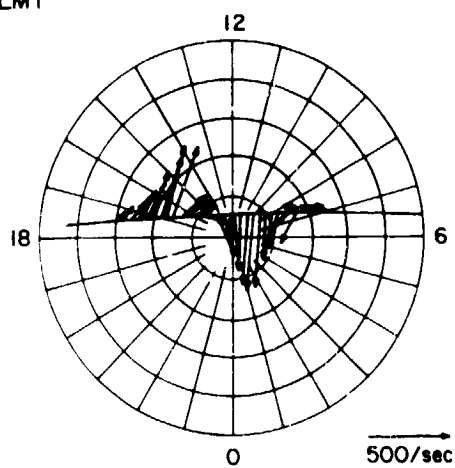
Figure 4. Expanded Plot of the Measurements by DE-2 While Crossing the Dusk Side of the Northern Auroral Oval During Orbit 1849. The top panel shows the total energy deposition rate by precipitating electrons. The second panel contains measurements of electron temperature (T_e) and the third panel shows the ion density (N_i). The zonal components of the ion and neutral winds (U_i and U_n respectively) are shown in the fourth panel. Positive zonal winds are sunward. The meridional component of the neutral wind (V_n) is shown in the fifth panel. Positive winds are parallel to the satellite velocity vector (dawn to dusk). Shown in the sixth panel are the vertical components of the ion and neutral winds (W_i and W_n respectively). In the seventh panel the temperature of the neutral atmosphere (T_n) as measured by the WATS[5] instrument is shown. In the bottom panel, the densities of N_2 and O are shown. These densities have been normalized to an altitude of 300 km by assuming hydrostatic equilibrium. The invariant latitude, universal time, altitude, magnetic local time, and geographic latitude are given at the bottom.

DE-FPI/WATS NEUTRAL WIND VECTORS

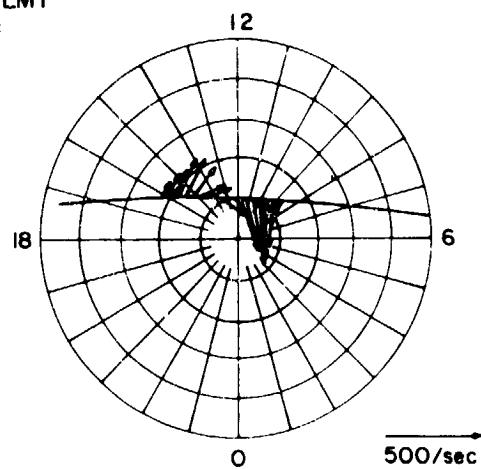MLAT/LMT
ORBIT:
1849

MLAT/LMT
ORBIT:
1847

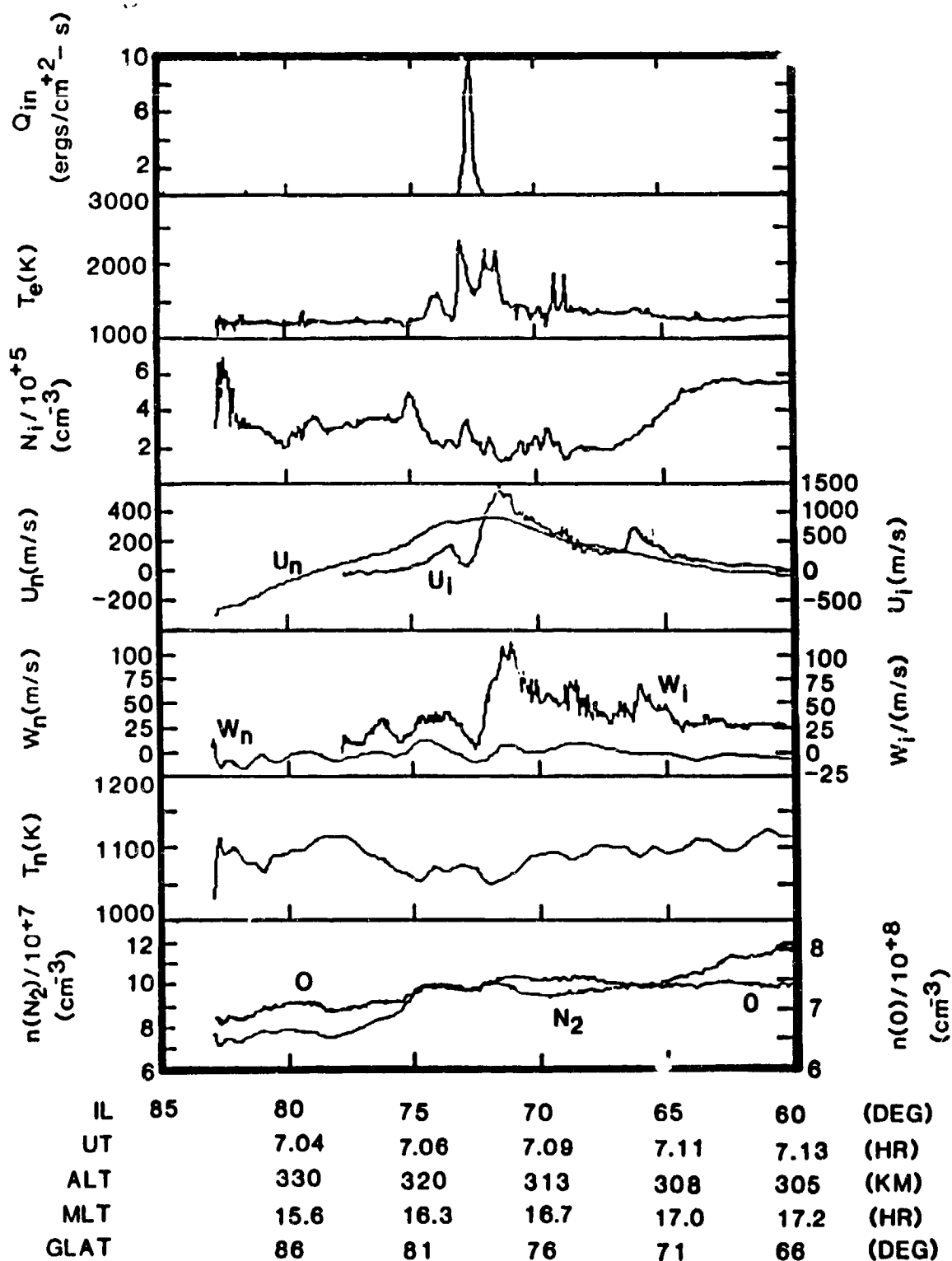Figure 5. Polar Plots of the Neutral Winds Measured During Orbits 1849 and 1847.

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Figure 6. Expanded Plot of Measurements from Dusk Auroral Oval During Orbit 1848. See the caption of Figure 4 for an explanation of each panel.
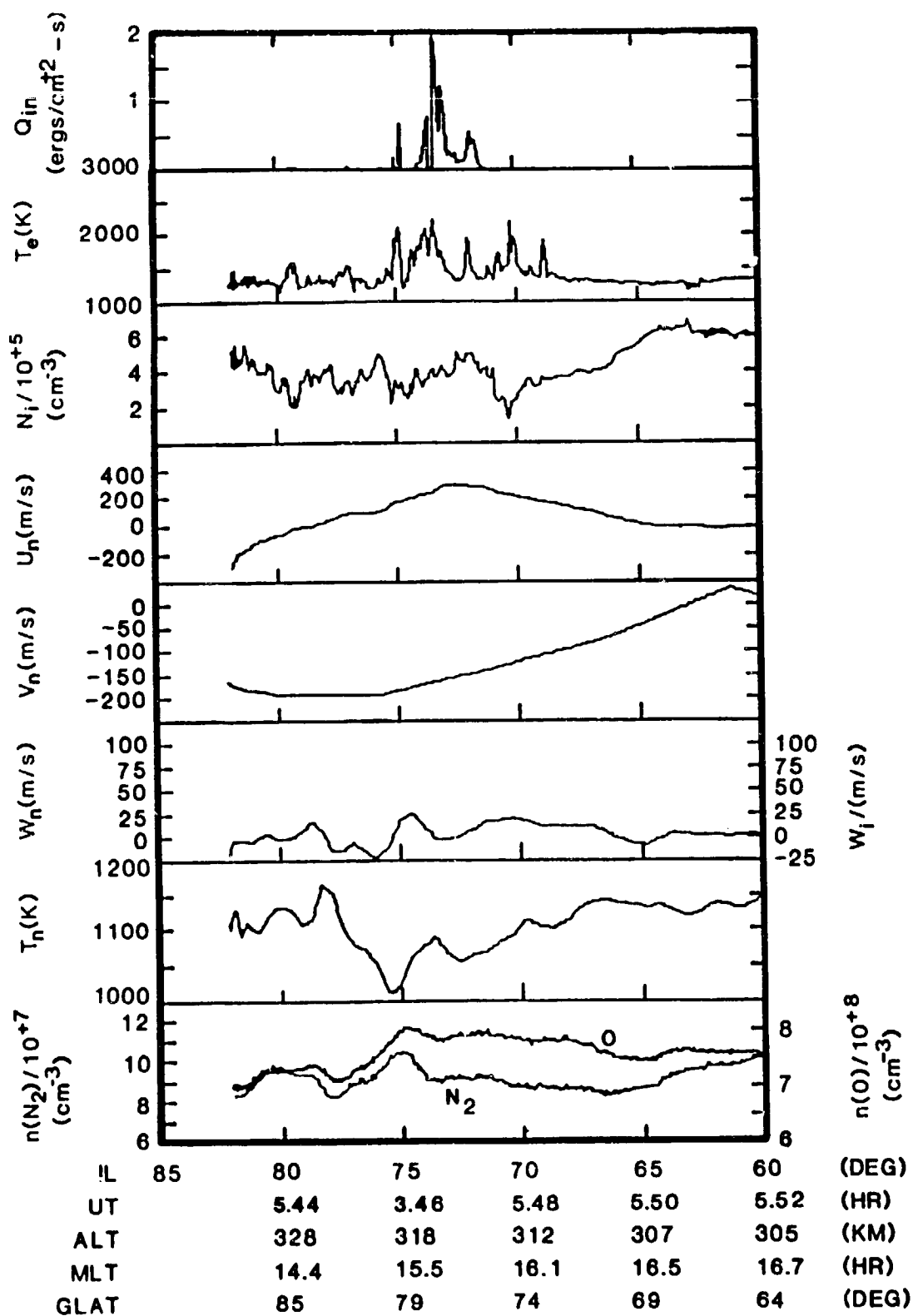
Figure 7. Expanded Plot of Measurements from Dusk Auroral Oval During Orbit 1848. See the caption of Figure 4 for an explanation of each panel.

The published models[1,2,4] would seem to predict a temperature increase on the order of 10 K, not a decrease. However, the model by Walterscheid *et al.*[4] does give a temperature decrease when extended to higher altitudes (>240 km) [L. Lyons, personal communication, 1987].

Although the measured zonal neutral wind velocities are larger than those modeled, the measured velocities might result from the stronger electric field and higher ion densities observed. The electric field in the dusk auroral oval (50 - 75 mV m^{-1}), as derived from the ion winds, is slightly stronger than that used in either the Fuller-Rowell[1,2] or the Walterscheid *et al.*[4] models (see Table 1 and Figure 1). However, increased forcing from a stronger electric field will not necessarily lead to higher neutral wind velocities due to the resulting cross winds.[2] In Table 1 the data and model calculations are compared in more detail.

Table 1. Comparison of Models and Observations

Parameter	SS@	FR^	WS#	Data
E$_{max}$ (mV m^{-1})	100	50	40	50 - 75
max N$_i$ (cm^{-3})	1 × 10^{5*}	2 × 10^{5*}	4 × 10^{5*}	—
	9 × 10^{4†}	1 × 10^{5†}	—	1 - 6 × 10^5
T$_\infty$ (K)	1000	700	1000	~1200
elapsed time of results	equilibrium	3 hours	1 hour	1.5 hours
delta T$_n$ (K)	—	+7*	<= +30*	-100
	—	+8†	—	—
U$_{max}$ (m s^{-1})	220*	300*	220*	—
(zonal wind)	200†	240†	—	300-600
V$_{max}$ (m s^{-1})	—	13*†	16*	—
(meridional wind)				
W$_{max}$ (m s^{-1})	—	~10*†	~10*	<30
(vertical wind)				
mean mass	—	1.02	—	—

@ model by St. Maurice and Schunk[3] using electric field shown in Figure 1.
^ dawn sector from Fuller-Rowell[1,2] using electric field shown in Figure 1.
# Walterscheid *et al.*[4] model (240 km is maximum altitude) using electric field shown in Figure 1.
* value at 240 km
† value at 320 km

6. CONCLUSIONS

The most notable observation is the minimum in the neutral temperatures. This minimum appears in the discrete auroral arc observed during all three orbits and it is correlated with the maximum in the zonal wind velocity, indicating that it may be a dynamical effect. More work is necessary to determine the mechanism responsible for this minimum; however, a divergence in the neutral winds poleward of the maximum winds is suggestive. Atmospheric cooling might result from such a divergence of the winds.

Qualitative agreement between models and observations is seen in the neutral wind velocities. More detailed comparisons, using the models with the observed parameters, are needed since the effect of simultaneously increasing the density of the neutral atmosphere, strength of the electric field, and density of ions is not trivially apparent.

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2. Fuller-Rowell, T.J. (1985) A two-dimensional, high-resolution, nested-grid model of the thermosphere 2. Response of the thermosphere to narrow and broad electrodynamic features, *J. Geophys. Res.* **90**:6567-6586.

3. St. Maurice, J.P. and Schunk, R.W. (1981) Ion-neutral momentum coupling near discrete high-latitude ionospheric features, *J. Geophys. Res.* **86**:11299-11321.

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